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The severity of rust on apples in the Hudson River Valley during 1927 and 1928 has led to a reawakening of interest in this problem. Concern is felt more particularly for the reason that abundant infections on the fruit have added enormously to the usual losses caused by foliage infection. The attention of the writers was especially drawn to the problem in the summer of 1927 by the appearance of numerous fruit infections on the variety McIntosh, which formerly had been regarded as highly resistant. The need for additional study of cedar rust was emphasized by the fact that the symptoms on McIntosh and other varieties were so unusual as to place in question the identity of the disease on these varieties.

As these studies have progressed, it has become evident that not one, but three, rust diseases are destructive among the varieties of apples grown in the Hudson River Valley. Since these three diseases and no others are found extensively on both cedars and apples in this region, and since no other rust disease is known to be prevalent on the apple in eastern North America, we shall assume that the rust problem in apples in the Hudson River Valley is fully represented by them. Accordingly, in this paper the three diseases are considered more or less in parallel rather than consecutively, in order to facilitate comparison and diagnosis. To avoid confusion the three rust diseases are designated as apple rust caused by *Gymnosporangium juniperi-virginianae* Schw., hawthorn rust caused by *G. globosum* Farl., and quince rust caused by *G. germinale* (Schw.) Kern.

PLANTS AFFECTED

Weimer (1917) has studied these three diseases on cedars and certain rosaceous plants in New York, but apparently found only the apple rust on apples. He did not, however, make extensive observations in orchards. Stewart (1910), in earlier observations in eastern New York during the period from 1895 to 1910, records only the apple rust on cultivated apples.

Authors' acknowledgments. Several workers have been very helpful in supplying specimens and information and in some of the inoculation experiments. In addition to those named in the body of this paper, we mention especially Professor W. L. Doran and Messrs A. B. Buchholz, A. B. Burrell, E. J. Hambleton, S. C. Jones, A. S. Mills, and E. V. Shear.

While many species of plants[1] are affected by one or more or these diseases, the number of species which have any important relation to rust of apples in the Hudson Valley is apparently much smaller.

Cedars

All of the three fungi are generally distributed on the red cedar (*Juniperus virginiana* L.) in the telial stage, and two of them, *G. globosum* and *G. germinale*, are perennial on the cedar. *G. germinale* is more evenly and abundantly distributed through the cedar areas than the other two species, which tend to be localized near apple or hawthorn trees. *G. germinale* may occur also on the juniper (*Juniperus communis* L.), but the juniper is not commonly associated with fruit trees in eastern New York and we have not encountered it.

Apples and related plants

Our observation on the aecial stages of these fungi, most of them made in 1928, indicate that the following are the principal suscepts in the Hudson Valley: for *G. juniperi-virginianae*, apple; for *G. globosum*, hawthorn (many species) and apple; for *G. germinale*, quince, hawthorn, and apple. We have rarely found *G. globosum* on pears, and in no case causing severe disease on this plant.

PREVALENCE ON VARIETIES OF APPLES, AND LOSSES

Many lists of susceptible and resistant varieties of apples have been prepared, but a considerable variation exists among these. Whether this variation is due to differences in the observers, to differences in behavior of the disease or diseases in different localities, or to differences in the fungi which produce the diseases, cannot be stated with certainty. It is clear, however, that varieties in the Hudson Valley which have until recently been rated as highly resistant, are now showing approximately as great an incidence of rust as are other varieties which are generally regarded as highly susceptible. It is apparent also that we are dealing with three distinct diseases, two of which are probably rare in many localities in which observations have been made. Another cause of the apparent or actual divergence of our records from those of earlier workers is the fact that we have given comparatively greater attention to infection of fruit than to that of foliage.

In the herbaria of the Department of Plant Pathology at Cornell University are two specimens of quince rust on apple fruit and three specimens of hawthorn rust on apple foliage, all from New York State. The earliest date for the quince rust is 1903, and the earliest of the hawthorn-rust collections was made in 1908.

[1] Kern (1912) has assembled comprehensive lists of the species of plants known to be affected by these diseases. A few additions have been made since the publication of those lists.

Only one published account has been found to indicate that hawthorn rust occurs commonly on cultivated apples. Thaxter (1891), working in Connecticut, states "that perhaps the most common orange rust of apples in this State is undoubtedly caused by this species [*G. globosum*]." Professor Thaxter recently stated (in a letter dated November 9, 1928) that *G. globosum* on apple seems to be commoner farther south in New England than it is in southern Maine, where it very seldom occurs on cultivated apples but is not uncommon on wild stock. Dr. F. D. Kern also states (in a letter dated October 10, 1928) that *G. globosum* is not uncommon on apple foliage in the New England States. He has obtained collections from Connecticut, Maine, Massachusetts, New York, and Vermont. The only printed account which we have found of quince rust as an important disease of the apple, is presented in two brief notes from Nova Scotia by Hockey (1926, 1927). Dr. W. G. Farlow reported, in conversation with Dr. F. D. Kern a number of years ago, that *G. germinale* was not uncommon on apple fruits in the vicinity of Boston (letter from Kern dated October 10, 1928). Unfortunately, no more detail seems to have been preserved. Mr. Hockey has kindly submitted the following notes in a letter of October 18, 1928:

> Previous to 1924, apple rust was reported from Nova Scotia as caused by *Gymnosporangium juniperi-virginianae* Schw. A very careful survey in subsequent seasons has established that this disease is caused by *G. germinale* (Schw.) Kern. The alternate host for this rust is *Juniperus communis* var. *canadensis* Loud., a very prevalent plant in waste pastures and rocky slopes in the Annapolis Valley.
>
> The Roestelia stage was identified on Amelanchier, Crataegus, *Cydonia* spp., and on Gravenstein apple. It has been observed fruiting on Bishop Pippins, but no specimens have been examined by the writer. The disease is commonly observed at the calyx end of the fruit, causing a dark green, seminecrotic area. Very few fruit infections produce aecia, and infections on apple foliage have not been positively identified. Rust has been observed on the following varieties of apples: Crimson Beauty, Yellow Transparent, Gravenstein, McIntosh, Fameuse, Ribston Pippin, Bishop Pippin, Wagener, Tompkins King, Stark, Baldwin, and Russet.
>
> Another species of rust found on the low bush juniper, locally, is *G. claveriaeforme* (Jacq.) D. C. Aecia of this species have been found on *Amelanchier* and *Crataegus* spp. but not on apple.
>
> The red cedar, *Juniperus virginiana* L., is to be found in very scattered areas in Nova Scotia, and no rust resembling a Gymnosporangium species has been reported on this host.

Specimens of Gravenstein apple fruits bearing pycnia of *G. germinale* have been received from Mr. Hockey.

In view of the lack of knowledge of the hawthorn and quince rusts on apples, records of fruit and foliage infection are given here in some detail. No records of actual percentage of infected fruit were made by the writers in 1927. However, it was estimated that up to 50 per cent of McIntosh fruit was infected in some orchards. A. S. Mills[2] reports

[2] Typewritten report of special field assistant, Departments of Plant Pathology and Entomology, Cornell University.

up to 8 per cent fruit infection on the McIntosh variety in Greene County at harvest time. W. E. Blauvelt[3] records 10 and 15 per cent fruit infection in several McIntosh orchards in Orange County. It is shown later, in this paper, that much of the infected fruit of this variety drops before harvest time. The remainder of the records presented here were taken during the season of 1928. Most of our observations of both cedar and apples were made in Columbia, Dutchess, Greene, Orange, and Ulster Counties.

In table 1 are given some counts of quince rust on apple fruits collected in fourteen orchards in four counties. It will be noted that most

TABLE 1. QUINCE RUST ON APPLE FRUIT

Variety	Number of counts*	Per cent of infected fruit	Notes
Fameuse	1	21	
Hubbardston	1	28	
McIntosh	15	18	1 to 59 per cent, pycnia only
Winesap	2	74	72 and 76 per cent
Yellow Transparent	1	84	Pycnia only
Delicious	3	60	Pycnia only

*Counts for the most part represent 50 or 100 fruits.

of the varieties included in the table are usually listed as resistant or immune to the apple rust. From the data it is evident that direct fruit infection alone is blamable for heavy losses.

In table 2 are shown some records of fruit infection by the apple-rust fungus. Even here the injury to the crop through direct infection of

TABLE 2. APPLE RUST ON APPLE FRUIT

Variety	Number of counts	Per cent of infected fruit
Jonathan	2	25
Rome Beauty	4	30
Esopus Spitzenberg	1	95
Sutton Beauty	1	27
Twenty Ounce	1	18
Wealthy	6	25
Winter Banana	2	12

[3] Typewritten report of special field assistant, Departments of Plant Pathology and Entomology, Cornell University.

the fruit is obviously considerable, a fact which, with a few exceptions (Giddings, 1918, and Gardner, 1925), has escaped emphasis in the literature of apple rust. The varieties Baldwin, Greening, Williams, and Wagener have been found free of fruit infection in orchards in which both apple and quince rusts were present, at least in small amounts.

With the varieties of apples that have been studied, the quince rust causes distinctly more injury to infected fruits than does the apple rust. With some varieties, a large proportion of the fruits affected by the quince rust may fall from the tree before harvest time, and often the remaining fruits are rendered worthless. On June 27, 1928, the fruit on a McIntosh tree showed 33 per cent infection, while 47 per cent of the dropped apples under the same tree were infected. Again, on September 11, 1928, the fruit on a Delicious tree and the drops from the same tree showed 51 and 97 per cent infection, respectively.

The data in table 3 illustrate in another way, in part, the loss due to

TABLE 3. DROPPING OF RUST-INFECTED FRUIT SHOWN BY SUCCESSIVE COUNTS ON THE SAME TREES, 1928

Variety	Rust	First count		Second count	
		Date	Per cent of infected fruit	Date	Per cent of infected fruit
Fameuse	Quince	July 5	21	Sept. 10	20
Hubbardston	Quince	July 5	14	Sept. 10	28
McIntosh	Quince	July 5	20	Sept. 10	6
McIntosh	Quince	June 27	14	Sept. 11	4
McIntosh	Quince	June 27	33	Sept. 11	8
McIntosh	Quince	June 28	31	Sept. 11	16
McIntosh	Quince	June 21	53	Sept. 10	28
McIntosh	Quince	June 27	65	Sept. 11	26
Jonathan	Apple	July 5	24	Sept. 10	38
Sutton Beauty	Apple	June 27	20	Sept. 11	27
Winter Banana	Apple	June 27	16	Sept. 9	14

fruit infection on several varieties. The second counts were made in each case on the same tree or trees as were the first counts. A wide variation in the dropping of fruit is seen, even among the varieties affected by the quince rust. This difference in behavior is apparently parallel with the type of injury rather than with the variety of apple or the species of fungus involved. The symptoms on McIntosh and Delicious fruits are distinctly necrotic in type, while those on the varieties other than McIntosh in table 3 are usually hyperplastic or hypoplastic.

No quince rust has been found on the foliage of apple, and no hawthorn rust has been seen on apple fruit. This is rather to be expected in view of the behavior of these diseases on hawthorn and quince. The hawthorn rust has appeared, however, with astonishing frequency on the collections of apple foliage which we have made (table 4). These collections

TABLE 4. APPLE AND HAWTHORN RUSTS ON APPLE FOLIAGE

Variety	Number of collections	Apple rust	Hawthorn rust	Size of spots	Notes
Baldwin	1	.....	+	Medium..	Slight
Ben Davis	1	+	.....	Large....	
Esopus Spitzenberg	2	.....	+	Small....	
Fameuse	2	.....	+	Small....	
Hubbardston	1	+	+	.....	Severe, mostly apple rust
Jonathan	1	+	+	.....	Moderate apple, slight hawthorn
McIntosh	8	.....	+	Small....	Mostly slight-moderate to severe one case
Northern Spy	1	.....	+	Small....	Slight
Northwestern Greening	1	.....	+	Medium..	Slight
Opalescent	1	+	.....	Large....	Slight to moderate
Rhode Island Greening	2	.....	+	Medium..	Slight
Rome Beauty	3	+	+	Large....	Trace hawthorn
Sutton Beauty	1	+	.....	Large....	Slight to moderate
Tolman Sweet	1	.....	+	Medium..	Moderate
Tompkins King	1	+	+	Small....	Slight
Twenty Ounce	1	+	.....	Large....	Severe
Wealthy	6	+	.....	Large....	Slight to severe
Winesap	1	.....	+	Medium..	Moderate to severe
Winter Banana	2	+	.....	Large....	Slight to severe

were made in six counties in eastern New York, and at one station each in Vermont and Massachusetts. Foliage of only one variety (Wealthy) has been received from Massachusetts. Six of seven specimens representing as many varieties from Orwell, Vermont, bore only hawthorn rust. In a few instances this disease may be classed as severe, but more often the spots are small and sparse, with few aecia. This may account for the fact that the disease has generally escaped attention. In addition to the records included in table 4, the hawthorn rust has been found on seedling apple trees in two localities in Tompkins County, central New York. In one of these cases the infection was severe and decidedly predominant over the apple rust. Two collections of seedling apple foliage from different localities in the Hudson Valley bore only apple rust.

An interesting observation was made on the natural infection of McIntosh and Wealthy foliage in an orchard near Hudson, New York. On adjacent trees, the number of spots per infected leaf, on June 27, 1928, was 3.7 on Wealthy and 8.7 on McIntosh (table 5). On the

TABLE 5. RUST SPOTS ON ADJACENT TREES, MCINTOSH AND WEALTHY, JUNE 27, 1928

Leaf no.	1*	2	3	4	5	6	7	8	9	10	11	12	13	14
Variety	Terminal													
Wealthy	1	0	0	0	0	0	4	3	2	6	4	4	2	....	....
Wealthy	2	0	0	0	0	0	1	3	5	8	8	6	5	0	....
Wealthy	3	0	0	0	1	0	1	5	8	4	1	2	1	....	....
Wealthy	4	0	0	0	0	5	3	10	4	7	1	6	2	0	1
Wealthy	5	0	0	0	0	0	1	1	0	1	8	7	5	3	1
McIntosh	1	0	0	0	0	0	0	11	26	20	6	1	....	....	....
McIntosh	2	0	0	0	0	0	2	15	10	11	6	4	0	7	....
McIntosh	3	0	0	0	0	0	4	10	4	11	1	11	....	....	....
McIntosh	4	0	0	0	0	3	10	20	16	8	2	1	0	....	....

*Youngest leaf.

McIntosh foliage, however, many of the infections had produced only small, pale areas, with a minute necrotic spot in the center. There was practically no defoliation on this variety, and yet only an occasional spot could be clearly distinguished on September 11. None of the spots had developed sufficiently to produce aecia; indeed, very few spots had progressed sufficiently to produce pycnia. At that time the Wealthy foliage presented the symptoms of a rather severe infection. From a comparison of the symptoms found here with those produced by artificial inoculations (described later), it seems probable that both the apple and the hawthorn rust were involved on McIntosh foliage, with the apple rust predominating. Here is apparently a case of resistance or hypersensitiveness similar to that encountered among the cereal rusts (Stakman, 1915) and elsewhere.

SYMPTOMS AND DIAGNOSTIC SIGNS

Considerable attention has been given by earlier workers to the symptoms produced by all these diseases on cedars (Weimer, 1917), and by apple rust on apples. It is not possible to give a complete treatment of the symptoms of quince and hawthorn rusts on the apple until observations can be made over a wider range of varieties and conditions. We shall consider here more particularly the characters which will be of service in diagnosing the diseases.

On foliage

Only the apple and hawthorn rusts have been found on apple foliage. On the upper (ventral) leaf-surface the spots are strikingly similar in appearance. However, on the varieties and seedling trees that have been studied, the hawthorn rust produces, on the average, distinctly smaller lesions (Plate I, 1), and none has been seen which equals in size those produced by the apple rust on a variety such as Wealthy. It is interesting to note that Wealthy foliage is highly resistant to hawthorn rust in inoculation experiments, the lesions produced being at most about 1 millimeter in diameter. On the lower (dorsal) leaf-surface, several distinguishing characters may be found. With the hawthorn rust the accia are relatively few in number and are closely aggregate in the center of the lesion, and the adjacent leaf tissue in the lesion is of a light orange color. The peridial tubes are persistent and long, sometimes reaching 3 to 5 millimeters in length (Plate I, 2). These dehisce irregularly, never becoming markedly revolute.

In contrast, the apple-rust spots bear numerous aecia scattered over the lesion, sometimes forming a ring near the margin of the lesion, and the peridia are strongly revolute, especially when moist (Plate I, 6).

The two diseases can be readily distinguished by examining the terminal cells of the peridia mounted in water (Plate I, 3, 4). The differences are by no means so striking if cells are taken from near the base of the peridial tube. The terminal cells of *G. juniperi-virginianae* are relatively long and narrow, separate readily in water, and are strongly curved. The comparable cells of *G. globosum* are irregularly lanceolate in face view, and adhere in a pseudoparenchymatous plate when mounted in water, curving slightly or not at all.

On fruit

The usual symptoms produced by apple rust on apple fruit are well known. Gardner (1925) has figured and described symptoms on Rome and Gideon fruits, however, which are strikingly different from those commonly encountered.

The quince rust on apple fruits presents a wide range of symptoms which on different varieties may be almost completely dissimilar, varying from hyperplastic to necrotic but in the main hypoplastic or necrotic (Plate II). There is less tendency here for the lesions to be restricted to the calyx end of the fruit, and often several separate infections are found on a single fruit (Plate II, 11). The surface of the lesion is usually of a dark green color, seldom if ever becoming orange on the varieties that we have studied.

The hyperplastic and hypoplastic lesions produced by the quince rust usually involve considerable areas of the fruit and may be accompanied in later stages by marked shriveling of the fruit (Plate II, 8).

The necrotic lesions involve less of the fruit surface, the fungus apparently being arrested at a comparatively early stage in the development of the fruit (Plate II, 9). Thus an older lesion sometimes resembles bitter pit in superficial appearance (Plate II, 7). Not infrequently the necrotic tissue cracks to a considerable depth, sometimes exposing the seed cavities. In the interior of the fruit the necrosis is more extensive and tends somewhat to follow the larger vascular elements (Plate II, 10). Aecia have not been found on the extreme necrotic type of lesion, and pycnia are not abundant. In the hyperplastic lesions, pycnia and aecia may be present in considerable abundance.

The most definite and striking diagnostic characters are found in the fruiting structures of the fungus. The pycnia, aecia, aeciospores, and peridial cells of *G. germinale* are distinctly larger than those of *G. juniperi-virginianae* or *G. globosum*. The aeciospores in mass are of a bright orange color, in contrast with the dull brown color of the spore mass in *G. juniperi-virginianae*. The peridium of *G. germinale* dehisces by irregular shredding and does not become revolute. The peridial cells are wet with difficulty and adhere in a pseudoparenchymatous plate when mounted in water. In face view these are distinctly verrucose (Plate I, 5), in contrast with those of *G. globosum* which in face view are comparatively smooth in the center and rugose at the margins (Plate I, 4 A).

ETIOLOGY

Kern (1912) has published detailed descriptions of the three fungi under consideration, in a monograph of the genus Gymnosporangium. Our findings agree in most of the essential details with those of Kern. It seems desirable, however, to present in this paper certain characters in somewhat greater detail.

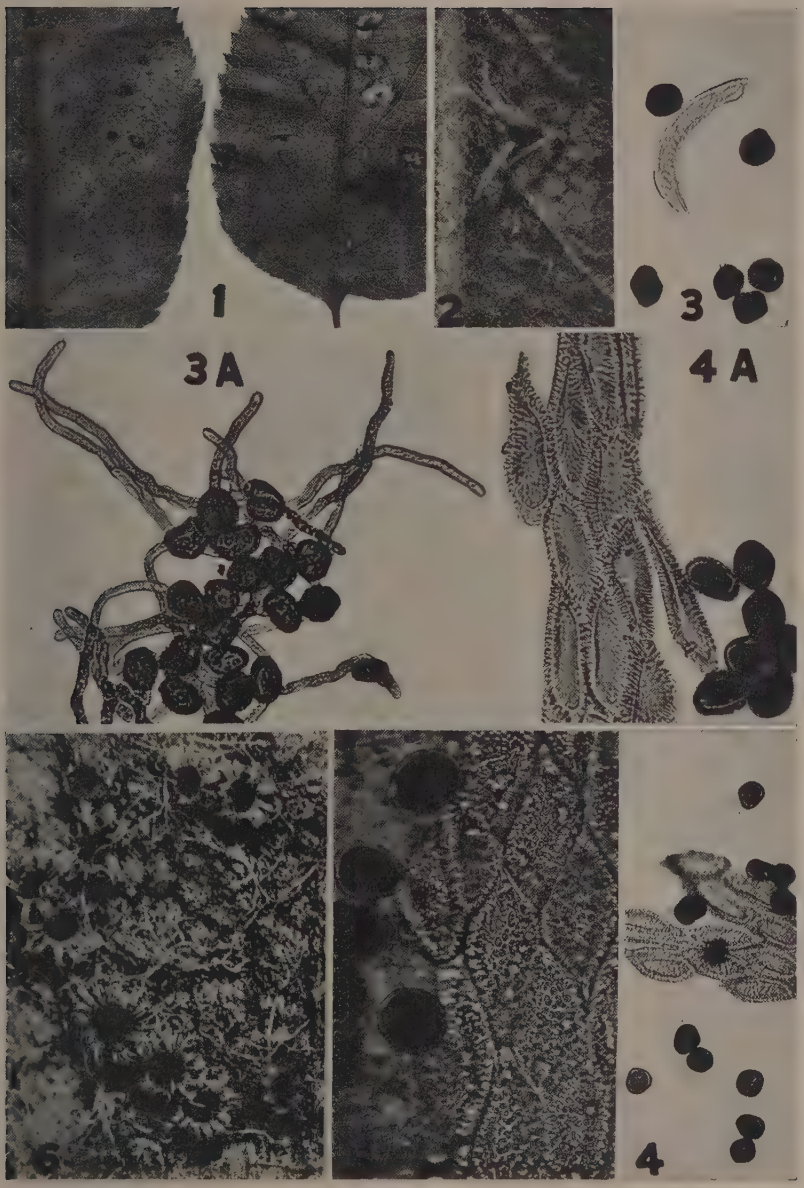
In figure 1 are shown the approximate frequency distributions of the three species in regard to length of aeciospores, based on measurements of 200 or more spores in each species. The aeciospores of *G. globosum* and *G. juniperi-virginianae* are similar in color and shape, and cannot be distinguished by casual examination. However, if 50 or more spores are measured and the mean length is computed, the two species are readily separated, since the mean length of *G. globosum* is roughly $21.60 \pm 0.17\ \mu$ while that of *G. juniperi-virginianae* is $27.45 \pm 0.01\ \mu$. The aeciospores of *G. germinale* have a mean length of $31.00 \pm 0.22\ \mu$, and in addition are lighter in color and more smoothly rounded than the spores of the other two species.

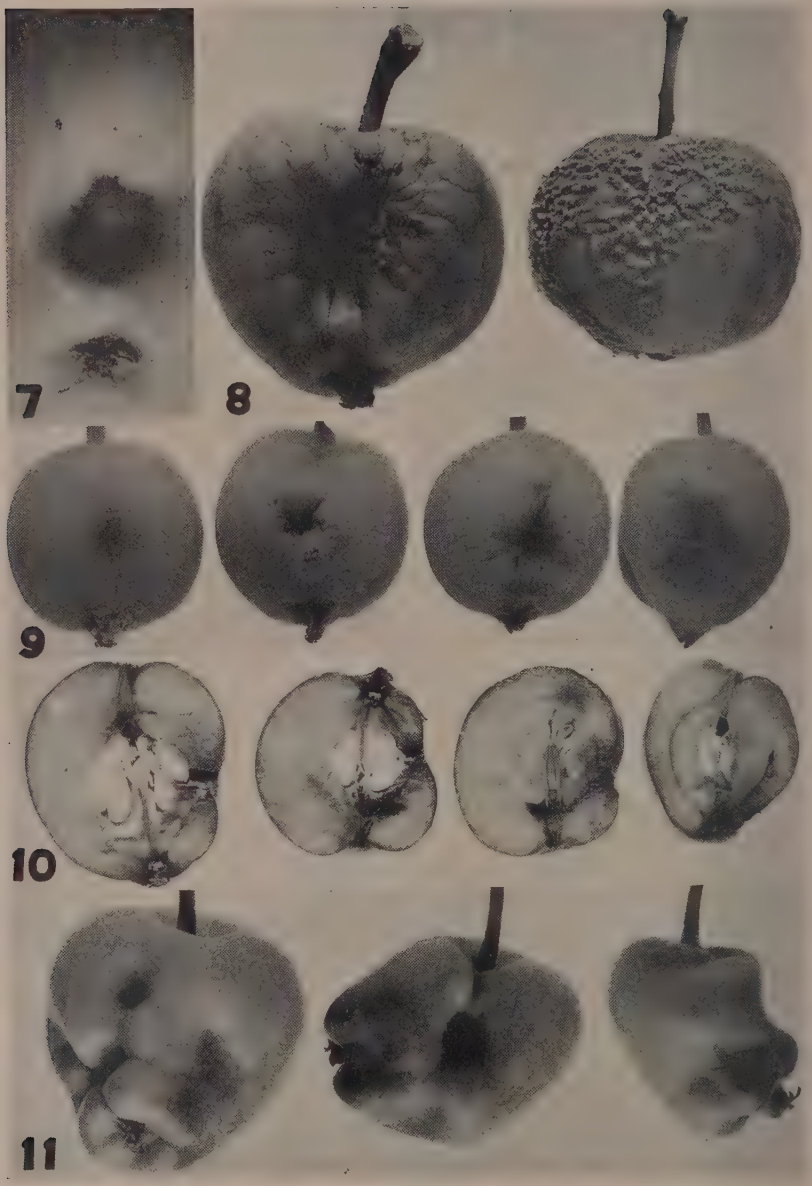
The aeciospores of the three species are more variable in width. The mean width of *G. globosum* aeciospores is $18.32 \pm 0.41\ \mu$, while that of *G. juniperi-virginianae* aeciospores is $22.67 \pm 0.51\ \mu$ and that of *G. ger-*

Plate I

AECIA, AECIOSPORES, AND PERIDIAL CELLS OF G. JUNIPERI-VIRGINIANAE, G. GLOBOSUM, AND G. GERMINALE

1, Apple rust (right) and hawthorn rust (left) on leaves of wild apple
2, Aecia of *G. globosum* on a leaf of the Tolman Sweet variety
3, Peridial cell and aeciospores of *G. juniperi-virginianae*. × 160
3 A, Germinating aeciospores of *G. juniperi-virginianae*
4, Peridial cells and aeciospores of *G. globosum*. × 160
4 A, Peridial cells and aeciospores of *G. globosum*. × 275
5, Peridial cells and aeciospores of *G. germinale*. × 275
6, Aecia of *G. juniperi-virginianas* on leaf of cultivated apple


1
2
3
3A
4A
6
4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8
9
10
11

Plate II

QUINCE RUST ON APPLE FRUITS

7, Quince-rust spot on McIntosh apple fruit as the fruit approaches mature size
8, Quince rust on fruits of Winesap (left) and Fameuse (right), showing necrotic, hypoplastic, and hyperplastic symptoms
9, Quince rust on young McIntosh fruits, showing necrotic symptoms and pycnia
10, Cross section of young McIntosh fruits affected by quince rust, showing necrotic symptoms in interior of fruits
11, Quince rust on Delicious fruits

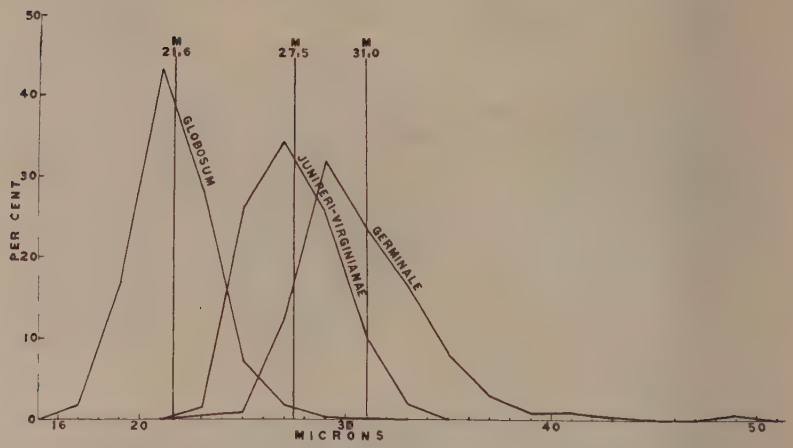

FIGURE 1. LENGTH OF AECIOSPORES

minale aeciospores is 26.88 ± 0.72 μ. Measurements of aeciospore width are less reliable as a means of identification.

An attempt was made to determine whether the spore dimensions of *G. globosum* are different on the comparatively resistant McIntosh apple from those on a susceptible species of Craetaegus. A slight decrease of both length and width on the resistant suscept was noted, but, with the number of spores measured, this decrease did not prove to be statistically significant.

The germination of aeciospores of these three species of fungi has been accomplished at best only with considerable difficulty (Reed and Crabill, 1915, and Weimer, 1917). Especially poor germination has been obtained by some workers toward the end of the growing season. A few casual attempts by the writers in late summer yielded negative results.

However, it was noted that lesions of the apple and quince rusts on apple fruits kept in a moist chamber at 3° C. for several weeks,[4] seemed to enlarge somewhat and to continue the production of aeciospores. An occasional aeciospore was found to have germinated in situ. Since Fukushi (1925) has shown that exposure to low temperatures increases the percentage germination of aeciospores of *G. yamadae* Miyabe, it seemed probable that a similar relation might obtain for the species *G. juniperi-virginianae* and *G. germinale*. Accordingly, aeciospores of these fungi were taken from the 3° chamber and mounted in raised drops of distilled water at room temperature on December 6, 1928. A

[4] The material of *G. germinale* was kept in the cold chamber for approximately twelve weeks, and that of *G. juniperi-virginianae* for about eight weeks.

considerable number of the spores of both species germinated. More extensive tests were then made at various temperatures, and the results were indeed surprising (table 6, and Plate I, 3 A). We find no record,

TABLE 6. GERMINATION OF AECIOSPORES FOLLOWING EXPOSURE TO LOW TEMPERATURES (3° C.)

Date of test	Temperature (centigrade)	*G. juniperi-virginianae*		*G. germinale*	
		Number of spores examined	Per cent germination	Number of spores examined	Per cent germination
December 6, 1928....	21°	800	80.5	529	32.5
December 6, 1928....	15°	800	79.6	764	20.5
December 14, 1928...	12°	400	74.7	400	20.7
December 18, 1928...	9°	900	63.5	800	23.3
December 18, 1928...	6°	300	21.3	400	12.7

in the literature, of germination approaching that recorded here for the aeciospores of these species. The germ tubes were vigorous, and reached a length of 400 to 600 μ in twenty-four hours, even at 9° C.

On December 14, fallen Crataegus fruits bearing *G. germinale* were collected at Ithaca, New York. The fruits were browned and more or less mummied in appearance, and the open aecia no longer contained spores. However, a few aecia were found which had never opened, and spores from these were mounted at 9°, 12°, and 15° C. for germination. Even here a germination of respectively 1, 2, and 3.5 per cent was obtained.

A single mount of aeciospores of *G. globosum* collected on December 12, 1928, on fallen Crataegus leaves, showed 54 per cent germination after twenty-six hours. The only appreciable germination reported for this species by Weimer (1917) was obtained from material exposed outdoors until November 8.

In view of these results and the successful inoculations made by Dodge (1918) and others, there seems no longer any reason to question that aeciospores of these fungi may produce infection during the season in which they are produced. It seems probable that the greater part of the natural infection on cedars will be found to take place in late autumn, rather than in midsummer or the following spring as has been suggested by various workers. Further studies are needed to provide direct evidence of the time and manner of infection of the cedar by each of these fungi.

It has been pointed out that the peridial cells of the three fungi differ in size as well as in shape and sculpturing (Plate I, 3, 4, and 5). The dimensions of these cells are more definitely recorded in figures 2 and 3.

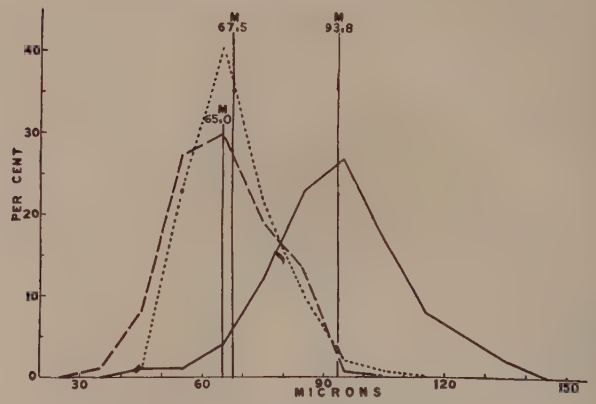

FIGURE 2. LENGTH OF PERIDIAL CELLS

——— *G. juniperi-virginianae*
— — *G. globosum*
..... *G. germinale*

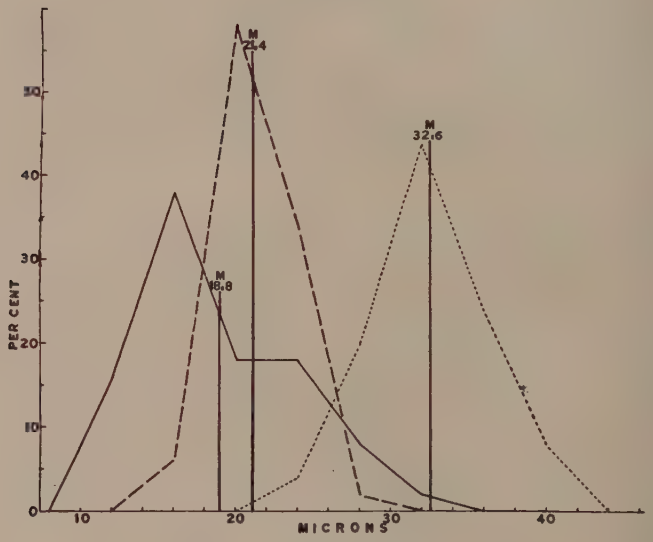

FIGURE 3. WIDTH OF PERIDIAL CELLS

——— *G. juniperi-virginianae*
— — *G. globosum*
..... *G. germinale*

These measurements were taken from cells rather toward the tip than toward the base of the peridium. There is a marked difference in size and shape between cells from the base and those from the tip of the same peridium, especially in *G. juniperi-virginianae*. This fact may account for the difference between these figures and those of Kern (1911).

The question of the existence of pathogenic strains among these fungi has received little attention, and no certain evidence bearing upon it has come out of this work. However, in view of the circumstantial evidence, including the variation in the results of inoculations with telial material from several sources, it seems desirable that this question be studied further.

Inoculation tests

It has been pointed out that this work was stimulated chiefly by the appearance on McIntosh apple fruits of a serious disease which for a time was not identified with certainty. When it seemed evident that the disease was a "cedar rust," several urgent questions arose. Chief among these was the question of determining which of the three rust diseases common on cedars in the Hudson Valley was blamable for the condition on McIntosh fruit. Accordingly, inoculations were made with the three fungi *G. juniperi-virginianae*, *G. globosum*, and *G. germinale*, on foliage of the McIntosh and Wealthy varieties in the greenhouse and on McIntosh fruit and foliage in the field.[5]

In seven fruit-inoculation trials involving several hundred fruits, no conclusively positive results were obtained. Most of these inoculations were made at least ten days after the blossoms had fallen, and were apparently later than the optimum period for natural infection.

On foliage, no infection was produced by *G. germinale* on McIntosh and Wealthy in the greenhouse (four trials) or on McIntosh in the field (four trials).

G. juniperi-virginianae was used to inoculate McIntosh foliage in the greenhouse and in the field in nine trials. Three inoculations were made on Wealthy in the greenhouse, for comparison. In two of the trials in the field, natural infection was not entirely excluded and hence no conclusive results were obtained from these. Of the remaining seven tests with McIntosh, six yielded infection varying from a few spots to as high as 74 spots on one leaf. In one test in the greenhouse, the infection on a McIntosh tree was sufficiently heavy to cause the dropping of several leaves in four weeks. These spots rarely reached a diameter of 1 millimeter, however, and for the most part merely developed into necrotic "flecks." Fukushi (1925) has shown that McIntosh foliage responds in a somewhat similar manner to infection

[5] As in the case of other workers (Kern, 1911), the most satisfactory infection was obtained by suspending the inoculum above the parts to be inoculated in a humid but not stagnant atmosphere.

by *G. yamadae*. No aecia of *G. juniperi-virginianae* have been found on McIntosh foliage from either artificial or natural infection. Inoculations on Wealthy foliage produced the usual symptoms associated with this fungus on a susceptible variety.

With *G. globosum*, ten inoculation tests were made on McIntosh foliage in the greenhouse and eight parallel tests were made on Wealthy. Six of the inoculations on McIntosh produced recognizable infection varying from a few spots to 46 spots on one leaf. On Wealthy, only one inoculation produced certain infection which was evidenced by a few minute orange spots (with pycnia) and many small necrotic spots. One other inoculation was followed by necrotic spots which resembled those of the preceding test but were not accompanied by pycnia or by orange color. Of three inoculations on McIntosh foliage in the field, two produced a small amount of infection but not equal to that produced by *G. juniperi-virginianae* in comparable tests.

In summary of the inoculation trials of McIntosh and Wealthy foliage, it is of interest to note that *G. germinale* did not infect either of these varieties, that *G. juniperi-virginianae* infected both varieties readily but the development of lesions in the McIntosh leaf was checked at an early stage, and that *G. globosum* infected both varieties but the Wealthy only with considerable difficulty.

During the latter part of the season of 1928, abundant rust material on a considerable number of varieties was available in the Hudson Valley. Thus a determination of the kind of rust involved was usually possible by the direct examination of aecia and pycnia of the fungi. Symptoms also were useful, within limits, as circumstantial evidence. As a result of all the evidence, it is concluded that the three diseases which are generally prevalent on the red cedar in the Hudson Valley are very common also on varieties of cultivated apples.

EPIPHYTOLOGY

The relations of rains and atmospheric humidity to infection, in the apple rust, are fairly well known. The relations in the hawthorn and quince rusts seem to be essentially similar. In the season of 1928, marked by a severe epiphytotic of all these diseases, the United States Weather Bureau Station at Hudson, New York, recorded, for the months of May and June, 1.69 and 7.89 inches of rain, respectively, as contrasted with 4.18 and 3.79 inches mean precipitation for that station. From May 18 to June 18 inclusive, 7.29 inches of rain was recorded, and from May 18 to June 6 there was never more than a one-day interval between rains. In 1927, when rust was rather severe, the rainfall was high in May (5.20 inches) and moderate in June (3.06 inches).

CONTROL

The control of apple rust by the eradication of the red cedar has been successfully practiced since the pioneer work of Jones (1893) and others. The similarities in the life histories of the three pathogenes, together with observations in orchards, suggest that the problem is essentially similar for the quince and hawthorn rusts. Considerable progress has already been made in cedar eradication by growers in the Hudson Valley, and a very considerable impetus will doubtless be given to this movement by the heavy losses of the past two seasons, not only on known susceptible varieties but on other varieties which have heretofore been considered practically free from rust. However, in a considerable number of cedar areas the cedar trees are in such great preponderance over the apple trees, or are held in such high esteem, that the method may still be considered impracticable. Compulsory state-controlled eradication of cedars has been employed in several cedar and apple areas in the Hudson Valley, but it has been attended by certain obvious difficulties.

Clearly, the most satisfactory solution of the problem lies in the eradication of the red cedar for a distance of at least one-half mile from apple trees, by individual growers or by neighbors in voluntary cooperation.

It has been stated that the apple and hawthorn rusts on cedars tend to be localized near wild apple and hawthorn. In some cases the removal of these plants from a cedar area would very markedly reduce the amount of inoculum produced by the cedars.

In areas where cedar eradication seems impracticable, the application of fungicides is the most promising alternate control measure. In two orchards, fruit of McIntosh were inclosed in paper bags on May 22, 1928, within a few days after the blossoming period (May 13 to 19). In each case the bagged fruits developed approximately the same amount of infection as did uncovered fruits on the same and adjacent trees. Thus, in 1928 at least most of the fruit infection on McIntosh was initiated before May 22 (about the time of the calyx application). This suggests that the susceptible period of fruit, for the quince rust, is passed in a relatively short time and during the time when applications of fungicide for scab control are most needed. In several orchards in which special attention was given to early spraying or dusting for scab control, on McIntosh particularly, the amount of fruit infection (rust) was low in comparison with other varieties and considering the exposure to sources of inoculum. In one instance a definite comparison was possible between adjacent rows of two blocks of McIntosh trees similar in size and in other respects except in the applications of fungicides. One block received four sprays (lime-

sulfur) before blossoming, followed by the calyx and two later applications. The other block received only one application of fungicide (sulfur dust) during the entire season. The percentages of fruit infection on September 12, 1928, were 1 and 12, respectively. It is evident, then, that a considerable reduction in fruit infection may be expected when experiments are made with the timely application of fungicides. In this connection, more information is urgently needed concerning the time of maximum susceptibility of the fruit.

SUMMARY

It has been shown that the cultivated apple in the Hudson River Valley of New York is affected by three distinct rust diseases. These diseases are designated as apple rust caused by *Gymnosporangium juniperi-virginianae* Schw., hawthorn rust caused by *G. globosum* Farl., and quince rust caused by *G. germinale* (Schw.) Kern.

Both the quince and the apple rust cause direct and serious losses by infection of the fruit.

Hawthorn rust is occasionally destructive on apple foliage.

Varieties of apples show marked variation in their response to the diseases, both in type of symptoms and in severity of the disease.

Symptoms of the diseases and morphological character of the fungi are presented as aids to diagnosis. The terminal peridial cells of the fungi offer a means of rapid determination of the fungi.

Good germination of aeciospores was obtained after exposure to low temperatures.

Inoculation experiments were made with the three fungi on McIntosh and Wealthy foliage. No infection was obtained with *G. germinale*. *G. juniperi-virginianae* easily effected ingress into the McIntosh leaf as well as that of Wealthy, but was usually checked in the McIntosh before pycnia were formed. *G. globosum* infected McIntosh fairly readily, and Wealthy only with difficulty.

Eradication of red cedars seems to be the best method of control for all of these diseases.

The application of fungicides offers some promise in the control of fruit infection.

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